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SIMULTANEOUS MULTIBEAM PHASE COMPENSATION. VIII. DESIGN AND LAB--ETC(U)

JUL 58 C J KRIEGER, R P KEMPFF

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6 **Simultaneous Multibeam Phase Compensation.**

~~VIII~~. DESIGN AND LABORATORY EVALUATION OF A PHASE COMPENSATOR FOR THE AN/SQS-4 MOD 3 SONAR. [redacted]

10 C. J. KRIEGER [redacted] B. P. KEMPFF

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THE PROBLEM

Evolve new techniques for sonars to improve low-frequency beam formation, reduce or eliminate mechanical beam steering by the application of electrical delay or phase compensation, and realize 100 per cent time utilization by simultaneous observation in all directions.

Specifically, this report deals with the design, construction, and evaluation of a new type of inductive phase compensator designed to compensate a circular array at a given frequency for simultaneous reception in a 360° sector.

RESULTS

1. A phase compensator was designed and constructed for the 32-inch diameter 48-element array of the AN/SQS-4 Mod 3 sonar. Its performance was determined in the laboratory by use of the Sonar Test Set TS-826/SQS-4 and the Target Signal Simulator Control C-1458/SQS-4.

2. The compensator produces 48 simultaneous identical beams uniformly spaced around the entire azimuth and having an angular resolving power more than sufficient to separate two sources differing by 7.5° in bearing. Resolution of the order of 1° should be possible using the amplitude ratio of adjacent beams.

3. The width of the main lobe is 8.5° at the half-power points, and the minor lobe level is about 21 db below that of the main lobe at 12 kc.

4. Satisfactory operation of the phase compensator throughout the frequency range from 10 kc to 14 kc was demonstrated, in good agreement with theory.

5. The transformer network of the phase compensator is relatively inexpensive, light, compact, and reliable. Its outputs lend themselves to simultaneous presentation and more effective detection and tracking of targets.

RECOMMENDATIONS

1. Develop a display system suitable for use with this phase compensator in detecting and tracking targets.

2. Use the phase compensator and its display system with a shipboard AN/SQS-4 Mod 3 sonar, in addition to the present video and audio display, and evaluate its performance.

ADMINISTRATIVE INFORMATION

Work on this phase compensator was carried on by members of the Special Research Division under AS 02101, NE 050962-21 (NEL L3-2) as a portion of the sonar techniques program.

The report covers work from January 1957 to April 1958 and was approved for publication 18 July 1958.

The phase compensator was designed by LT R. C. Olson, USN, and constructed by the NEL Magnetic Devices and Electronic Equipment Sections. J. Wong, L. D. Morgan, and J. A. Thomson took part in the laboratory evaluation. R. P. Kempff calculated the directivity patterns from the general theory of phase compensation.

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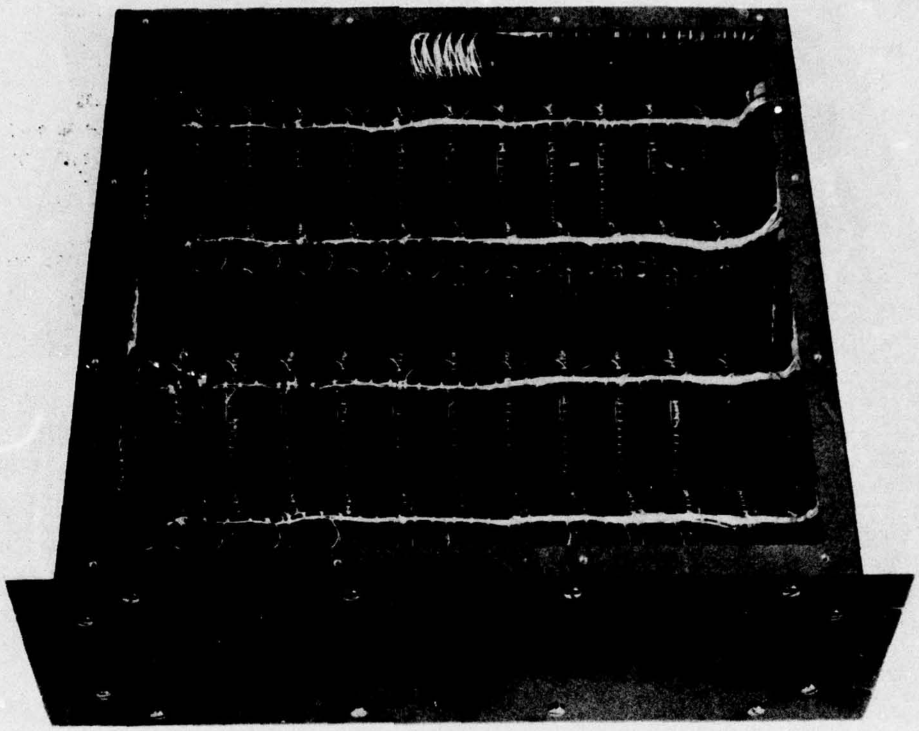

Figure 1. Phase compensator, top cover plate removed, front view.

PREFACE

This report is part VIII in the series on Simultaneous Multibeam Phase Compensation. Parts I and II appeared as NEL Report 632. Part III is NEL Report 642 and describes the pilot model and presents the first laboratory results. Part IV is NEL Report 670 and gives the results of more detailed laboratory tests of the pilot model, and in two appendixes presents the general theory and the mathematical theory of phase compensation of linear arrays. Part V is NEL Report 674 and describes a phase compensator for the AN/SQS-4 sonar and the results of a laboratory evaluation. The general theory of phase compensation of circular arrays is also presented. Part VI is NEL Report 757 and describes a phase compensator for use with a Lorad station keeping receiver system. Part VII is NEL Report 806 and describes a phase compensator for the AN/SQS-11 sonar and the results of a laboratory evaluation. The effect of various types of shading on the directivity pattern is examined analytically, and the mathematical theory of phase compensation of circular arrays is presented in a more elegant form.

The present report (part VIII) describes a phase compensator for the AN/SQS-4 Mod 3 sonar, using a further refinement in array shading. Results of laboratory evaluations in the frequency range from 10 kc to 14 kc are presented and compared with predictions based on the general theory of phase compensation.

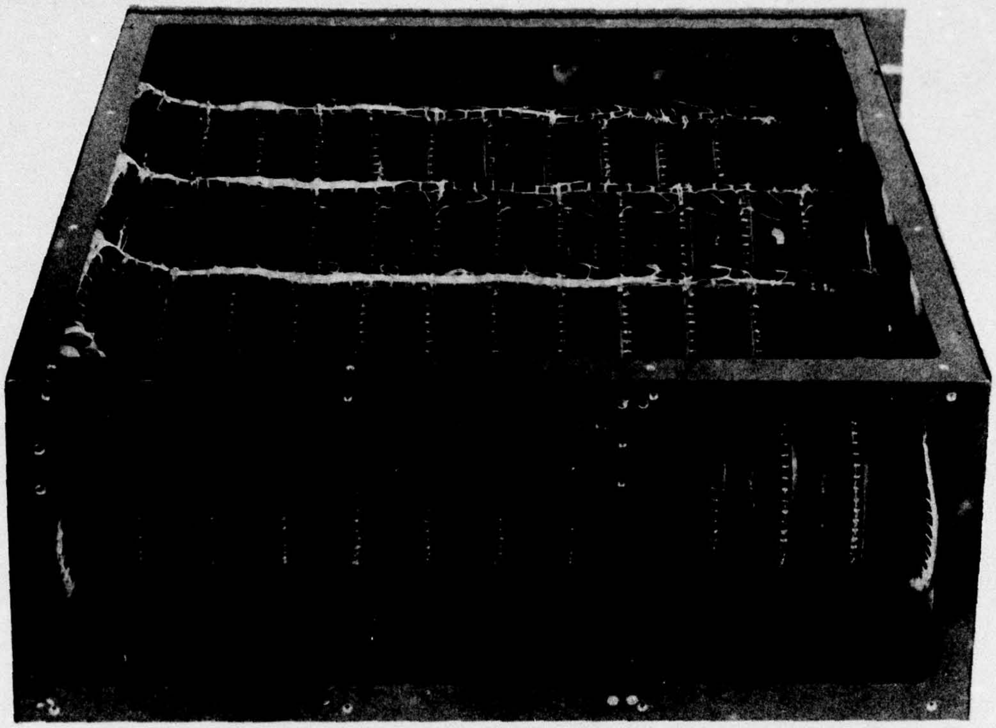

Figure 2. Phase compensator, top and rear cover plates removed, rear view.

INTRODUCTION

An earlier report[1] described the design and evaluation of a phase compensator for an AN/SQS-11 sonar array operating at 25.5 kc. The present report describes a similar compensator (figs. 1 and 2) designed for operation with the AN/SQS-4 Mod 3 sonar array at 12 kc. Aside from frequency, the present design differs from the previous one by incorporating a more advanced type of shading for further reduction of minor lobe levels.

The AN/SQS-4 Mod 3 array[2] consists of 48 elements spaced uniformly inside the periphery of a circle 32 inches in diameter. In the current model of the AN/SQS-4, only 16 of the 24 adjacent elements which lie symmetrically on the two sides of their axis of symmetry are used at one time to form a beam. The phase compensator described here can be used with the AN/SQS-4 in place of the delay lines and the sonar scanning switches. The chief advantage would be that reception would be continuous and simultaneous on 48 preformed beams, rather than on a time-sharing basis.

---

[1] C. J. Krieger and R. P. Kempff *Simultaneous Multibeam Phase Compensation, VII: Circular Array Phase Compensator for the AN/SQS-11 Sonar* (Navy Electronics Laboratory, Report 806) 26 September 1957.

[2] Bureau of Ships Navships 92283(A) *Instruction Book for Sonar Set AN/SQS-4*, CONFIDENTIAL, 29 June 1955.

TRANSFORMER DESIGN

As shown in the Appendix of Report 806,[1] compensation for sound arriving along the axis of symmetry is accomplished by multiplying each voltage vector by the quantity

$$\exp(-j\bar{\theta}_{0i}) = \cos\bar{\theta}_{0i} - j\sin\bar{\theta}_{0i}$$

where $\bar{\theta}_{0i} = kr\,[\cos(i \mp \tfrac{1}{2})\,7.5° - 1]$, and then adding the resulting voltages. The multiplication is carried out, as outlined in an earlier report of this series,[3] by applying the output voltage of each element to the primary of a transformer, whose secondary windings have turn numbers proportional to the cosine and sine of $\bar{\theta}_{0i}$ so that $N_c = k\cos\bar{\theta}_{0i}$ and $N_s = k\sin\bar{\theta}_{0i}$. The proper secondary windings are then connected in series, thus producing two voltages called X and Y. A 90° phase shift of Y and summation lead to $R = X - jY$, the directivity function of the array.

ARRAY SHADING

The appendix of reference 1 and another report of this series[4] show how minor lobes can be suppressed by reducing the responses of the elements near the array ends. LT R. C. Olson, USN, has proposed the use of cosine-squared type shading,[5] in order to effect a further reduction of minor lobe levels. This result is accomplished by modifying the number of turns of the secondary windings.

With 112 as the maximum number of turns of a secondary winding, and using a shading factor of $\cos^2(i \mp \tfrac{1}{2})7.5°$ we obtain

$$N_c' = \gamma_k^c \cdot 112 \cdot \cos^2(i \mp \tfrac{1}{2})7.5° \cdot \cos\bar{\theta}_{0i}$$

and

$$N_s' = \gamma_k^s \cdot 112 \cdot \cos^2(i \mp \tfrac{1}{2})7.5° \cdot \sin\bar{\theta}_{0i}$$

where $\bar{\theta}_{0i} = kr[\cos(i \mp \tfrac{1}{2})7.5° - 1]$

The factors γ_k^c and γ_k^s are coupling correction factors which compensate for low coefficients of coupling of small numbers of turns of a winding.

The resulting numbers of turns are shown in table 4 and figure 27 of reference 5, and are listed in table 1 below.

---

[3] C. J. Krieger *Simultaneous Multibeam Phase Compensation, V: Circular Array Inductive Compensator Evaluation* (Navy Electronics Laboratory, Report 674) CONFIDENTIAL, 3 April 1956.

[4] C. J. Krieger and R. P. Kempff *Simultaneous Multibeam Phase Compensation, VI: Phase Compensation for Lorad Station Keeping Receiver System* (Navy Electronics Laboratory, Report 757)Appendix C, CONFIDENTIAL, 7 May 1957.

[5] Olson, R. C. *Phase Compensation of Sonar Arrays.* M. S. Thesis, U. S. Naval Postgraduate School, CONFIDENTIAL, 1957.

TABLE 1. Calculated values of $\bar{\theta}_{0i}$, cos $\bar{\theta}_{0i}$, sin $\bar{\theta}_{0i}$, shading factor, and actual number of turns wound on transformer secondaries.

i	$\bar{\theta}_{0i}$	cos $\bar{\theta}_{0i}$	sin $\bar{\theta}_{0i}$	Shading Factor	Coupling Correction Factors γ_k^c	γ_k^s	N_c'	N_s'
12	−1098.63	+.94758	−.31951	.00428	1.94	2.15	+1	−1
11	−946.18	−.69235	+.72156	.03806	1.22	1.20	−4	+4
10	−797.65	+.21388	−.97686	.10332	1.28	1.05	+3	−12
9	−655.59	+.43182	+.90196	.19562	1.07	1.04	+10	+21
8	−522.43	−.95337	−.30182	.30866	1.03	1.06	−34	−11
7	−400.44	+.76116	−.64856	.43474	1.03	1.03	+38	−33
6	−291.71	+.37002	+.92902	.56526	1.04	1.02	+24	+60
5	−198.11	−.95043	+.31095	.69134	1.01	1.04	−75	+25
4	−121.23	−.51852	−.85506	.80438	1.03	1.01	−48	−78
3	−62.38	+.46355	−.88607	.89668	1.03	1.01	+48	−90
2	−22.58	+.92332	−.38403	.96194	1.00	1.03	+99	−42
1	−2.52	+.99904	−.04391	.99572	1.00	1.11	+112	−5
−1	−2.52	+.99904	−.04391	.99572	1.00	1.11	+112	−5
−2	−22.58	+.92332	−.38403	.96194	1.00	1.03	+99	−42
−3	−62.38	+.46355	−.88607	.89668	1.03	1.01	+48	−90
−4	−121.23	−.51852	−.85506	.80438	1.03	1.01	−48	−78
−5	−198.11	−.95043	+.31095	.69134	1.01	1.04	−75	+25
−6	−291.71	+.37002	+.92902	.56526	1.04	1.02	+24	+60
−7	−400.44	+.76116	−.64856	.43474	1.03	1.03	+38	−33
−8	−522.43	−.95337	−.30182	.30866	1.03	1.06	−34	−11
−9	−655.59	+.43182	+.90196	.19562	1.07	1.04	+10	+21
−10	−797.65	+.21388	−.97686	.10332	1.28	1.05	+3	−12
−11	−946.18	−.69235	+.72156	.03806	1.22	1.20	−4	+4
−12	−1098.63	+.94758	−.31951	.00428	1.94	2.15	+1	−1

FORMATION OF SIMULTANEOUS MULTIBEAMS

As discussed under Transformer Design, a single beam is formed by connecting the proper secondary windings in series, introducing a 90° phase shift and adding the two resulting voltages. Because of symmetry, this beam will be directed along the axis of symmetry of the 24 adjacent elements used. If the element at the left end, say No. 1, is omitted and the next element, say No. 25, is added and a new set of secondary windings connected, then the new axis of symmetry, and hence the new beam, will be directed 7.5° to the right of the original direction. Since this process can be employed 48 times, 48 simultaneous beams spaced 7.5° will result.

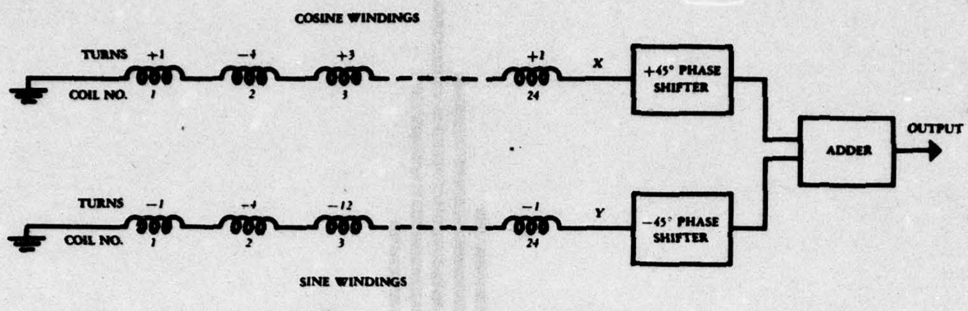

Figure 3. Diagram of series connection of secondary windings. Main lobe at relative bearing 090°.

Figure 3 shows the series connections of the secondary windings of coils 1 to 24 used in forming a beam in relative bearing 090°. The phase shift and addition networks are incorporated in the AGC amplifiers. A complete winding schedule for all coils is given in figure 27 of reference 5.

CONSTRUCTION OF THE PHASE COMPENSATOR

The Arnold Engineering Company cores D-927/56-3 with a specified inductance of 156 millihenries per 1000 turns were used for the 48 transformers. All primaries have 224 turns. The wire size is AWG30 for both primaries and secondaries. The assembly proceeded in a manner corresponding to that shown in figures 4 through 9 of reference 1.

The 48 input signals and the 48 pairs of output signals (2 for each beam) enter and leave the chassis through three 50-pin receptacles in the back.

LABORATORY EVALUATION

Preliminary laboratory evaluations were made by applying an input signal of 12 kc to a primary and measuring those *X* and *Y* outputs which contained one of the secondaries on the energized toroid. The measured voltages should be proportional to the number of turns. Polarity of the windings was checked by energizing two toroids and measuring the increase or decrease of the combined output which depends both on the number of turns and their polarity.

The final laboratory evaluation was made with the Sonar Test Set TS-826/SQS-4 and the Target Signal Simulator Control C-1458/SQS-4. The sonar test set puts out 16 voltages differing in amplitude and phase, and simulates the output voltages of 16 adjacent staves of an AN/SQS-4 Mod 3 transducer when a plane acoustic wave reaches it from a given bearing. These voltages are first amplified in preamplifiers and then go to the scanning switches of the AN/SQS-4 Mod 3 which provide the necessary delays for video presentation on the PPI scope and for the 800-cps audio output. For our test, the preamplifier outputs were connected to the phase compensator inputs, without disconnecting the scanning switches.

The responses of the 48 phase compensator channels or beams, after phase-shifting and adding, were amplified and presented on a VTVM and oscilloscope.

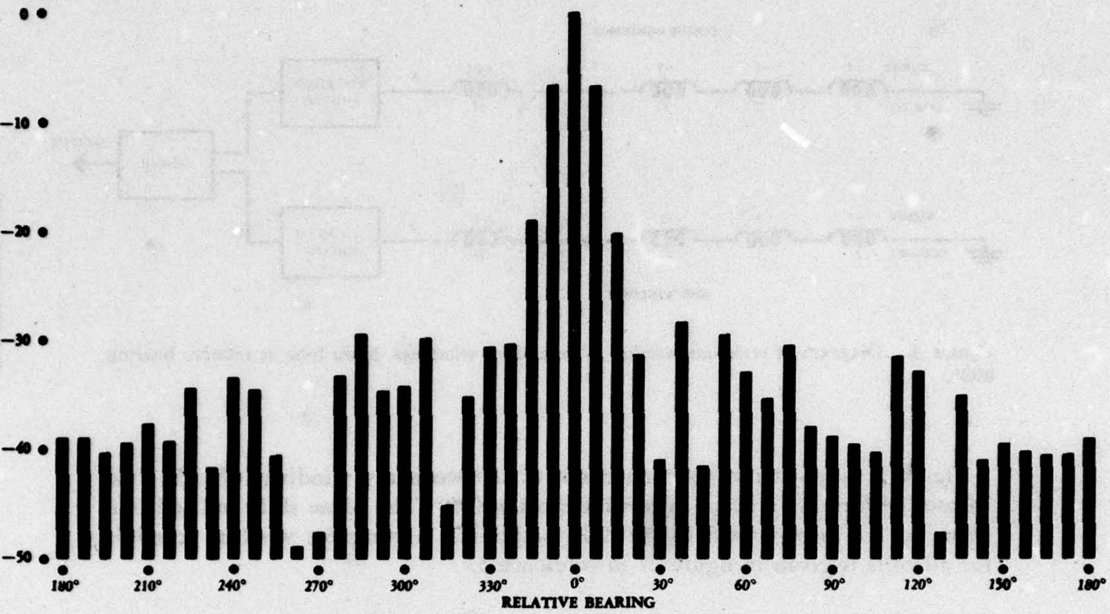

Figure 4. Response of 48 channels to simulated plane wave arriving from relative bearing 000°.

A typical result is shown in figure 4. The maximum response is at 000°. The output voltages of the adjacent beams are down over 6 db, and the remaining outputs are down an average of approximately 35 db.

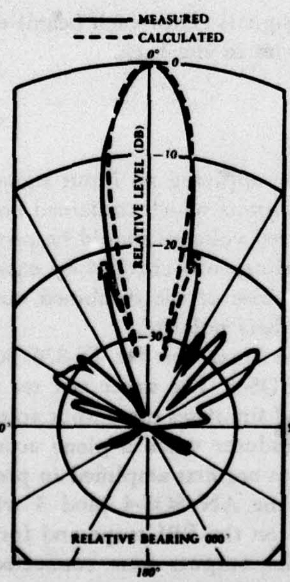

Figure 5. Directivity pattern of an AN/SQS-4 sonar operated at 12 kc using phase compensator.

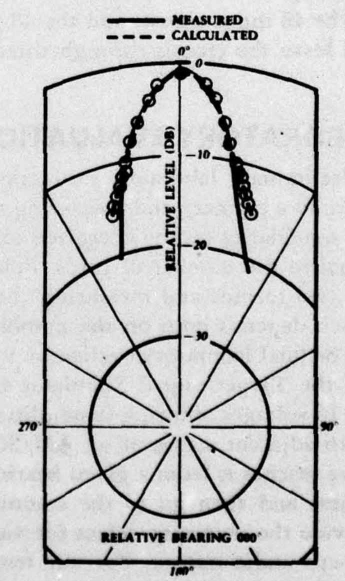

Figure 6. Directivity pattern of an AN/SQS-4 sonar operated at 10 kc using phase compensator.

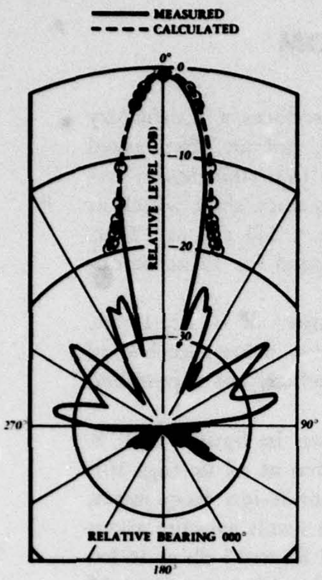

Figure 7. Directivity pattern of an AN/SQS-4 sonar operated at 11 kc using phase compensator.

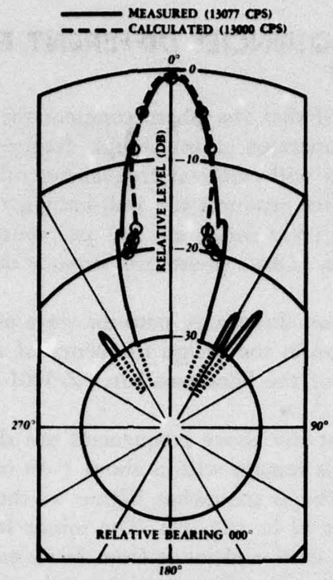

Figure 8. Directivity pattern of an AN/SQS/4 sonar operated at 13 kc using phase compensator.

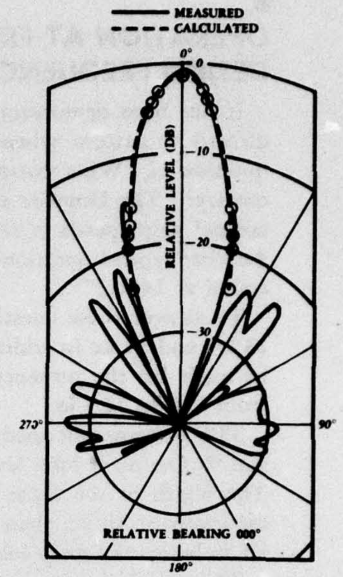

Figure 9. Directivity pattern of an AN/SQS-4 sonar operated at 14 kc using phase compensator.

A directivity pattern for relative bearing 000° was measured by varying the direction of arrival of the simulated plane wave slowly and recording the output on a graphic level recorder. The beam width at the half-power points is approximately 8.5° and the minor lobe level is about 21 db. The maximum response is at indicated relative bearing 000° corresponding to the direction of arrival of the simulated plane wave (fig. 5).

According to theory, the response of an array with cosine-square law shading and cosine law element response is defined by (equation 24 of reference 5):

$$R = \sum_{i=-N/2}^{+N/2} E_i \cdot \cos^2 (i \mp \tfrac{1}{2})\beta \cdot \cos [\theta - (i \mp \tfrac{1}{2})\beta] \cdot e^{j(\bar{\theta}_i - \bar{\theta}_{0i})} \qquad (1)$$

Here θ is the direction of arrival of sound measured from the axis of symmetry; and

$$\bar{\theta}_i = kr\{\cos [\theta - (i \mp \tfrac{1}{2})\beta] - 1\} \qquad (2)$$

$$\bar{\theta}_{0i} = kr\{\cos (i \mp \tfrac{1}{2})\beta - 1\} \qquad (3)$$

$$\beta = \frac{180°}{N} = 7.5° \qquad (4)$$

The calculated pattern in the vicinity of the main lobe is also shown in figure 5, and the agreement with the experimental results is very satisfactory.

OPERATION AT FREQUENCIES DIFFERENT FROM DESIGN FREQUENCY

It has been demonstrated that the phase compensator produces a satisfactory directivity pattern when operated at the design frequency, but an often asked question is, "What pattern will result at frequencies other than the design frequency?" The Doppler effect produces the well-known frequency shift which at normal ship speeds is relatively small, say ± 2 per cent or ± 240 cps at 12 kc. Another typical question is, "Can a phase compensator designed for 12 kc be operated at 14 kc?"

To answer these questions, directivity patterns were obtained at 10 kc, 11 kc, 13 kc, and 14 kc in addition to the design frequency of 12 kc. Allowance had to be made for the presence of the band-pass filter Z-5001-1 which has a passband from 11.7 to 12.3 kc.

The patterns obtained at the above frequencies are shown in figures 6, 7, 8, and 9. The main lobe levels remain within about 1 db of that at 12 kc (fig. 10). The width of the main lobe is somewhat higher at the nondesign frequencies, especially at 10 kc, than at 12 kc (fig. 11). The minor lobe levels average about 20 db below the main lobe level, and range from 24 db at 11 kc to 15 db at 14 kc.

Thus, this phase compensator operates satisfactorily within the range from 10 kc to 14 kc. Measurements outside this band could not be made since the rejection in the band-pass filter could not be compensated for by higher amplifier gains because of amplifier noise. An extension of the measurements to frequencies farther removed from the design frequency should be informative.

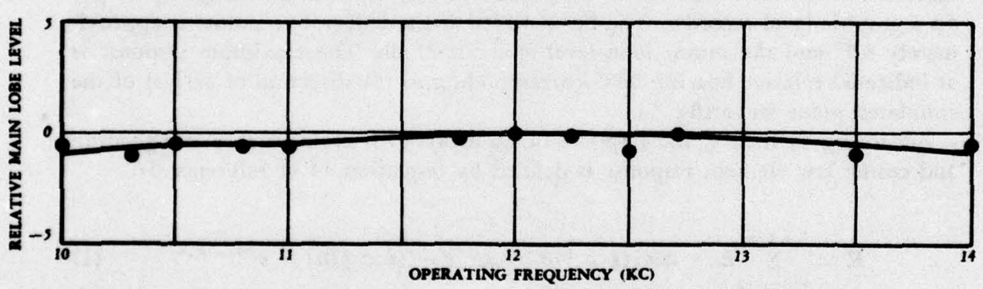

Figure 10. Main lobe level as function of operating frequency (measured).

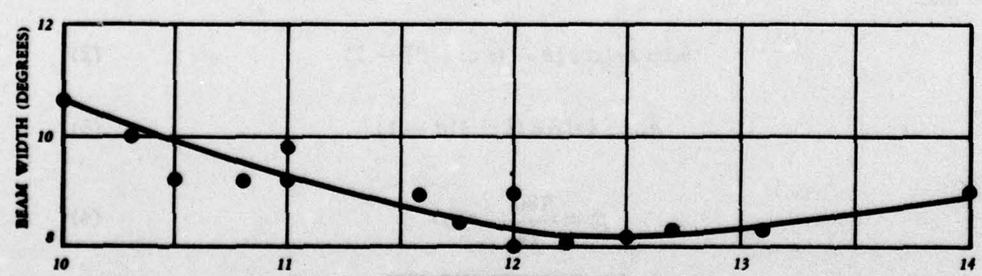

Figure 11. Beam width of main lobe at half-power points as a function of operating frequency (measured).

The compensator's relative independence of changes in frequency was considered of sufficient importance to treat the problem analytically.

When the operating freqency is f', then equation (2) becomes

$$\bar{\theta}_i = k'r\{\cos[\theta - (i \mp \tfrac{1}{2})\beta] - 1\}$$

where $k' = 2\pi f'/c$ and $\beta = 7.5°$, while equation (3) for $\bar{\theta}_{0i}$ remains unchanged with $k = 2\pi f/c$ where f is the design frequency.

With the newly defined $\bar{\theta}_i$ equation (1) is still applicable, but can be transformed for convenience in calculation as follows:

$$R = \sum_{i=-12}^{+12} \cos^2 (i \mp \tfrac{1}{2})\beta \cdot \cos[\theta - (i \mp \tfrac{1}{2})\beta]$$

$$\cos kr \left\{ \frac{f'}{f} \cos[\theta - (i \mp \tfrac{1}{2})\beta] + \left(1 - \frac{f'}{f}\right) - \cos(i \mp \tfrac{1}{2})\beta \right\} \tag{5}$$

$$+ j \sin kr \left[\frac{f'}{f} \cos[\theta - (i \mp \tfrac{1}{2})\beta] + \left(1 - \frac{f'}{f}\right) - \cos(i \mp \tfrac{1}{2})\beta \right]$$

Equation (5) was employed to calculate the directivity patterns in the vicinity of the main lobe at 10, 11, 13, and 14 kc. The computed values are shown as circles in figures 6, 7, 8, and 9. The general agreement between measurements and theory is quite satisfactory. The main and minor lobes are well reproduced by the simple theory with the exception of the low minor lobes at 11 kc, as pointed out earlier. The differences between measured and calculated values are attributed to failure to represent the experimental setup precisely by the assumptions made in the analytical treatment.

CONCLUSIONS

1. A phase compensator was designed and constructed for the 32-inch diameter 48-element array of the AN/SQS-4 Mod 3 sonar. Its performance was determined in the laboratory by use of the Sonar Test Set TS-826/SQS-4 and the Target Signal Simulator Control C-1458/SQS-4.

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5. The transformer network of the phase compensator is relatively inexpensive, light, compact, and reliable. Its outputs lend themselves to simultaneous presentation and more effective detection and tracking of targets.

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1. Develop a display system suitable for use with this phase compensator in detecting and tracking targets.

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A modification of the circular array phase compensators described in previous reports of this series was designed and constructed for use with the AN/SQS-4 Mod 3 Sonar array, and was evaluated in the laboratory. The new compensator operates satisfactorily through the 10-to-14-kc range, and its minor lobe levels have been reduced to 21 db below that of the main lobe. It also offers the same general advantages as its predecessors.

1. Phase compensation
2. Model AN/SQS-4 Mod 3
I. Krieger, C. J.
II. Kempff, R. P.

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Commander in Chief, U. S. Pacific Fleet
Commander in Chief, U. S. Atlantic Fleet
Commander Operational Development Force, U. S. Atlantic Fleet
Commander Submarine Force, U. S. Pacific Fleet
Commander Submarine Force, U. S. Atlantic Fleet
Commander Submarine Development Group TWO
Commander, U. S. Naval Air Development Center (Library)
Commander, U. S. Naval Air Missile Test Center (Technical Library)
Commander, U. S. Naval Air Test Center (NANEP) (2)
Commander, U. S. Naval Ordnance Laboratory (Library) (2)
Commander, U. S. Naval Ordnance Test Station (Pasadena Annex Library)
Commander, U. S. Naval Proving Ground
Commanding Officer and Director, David Taylor Model Basin (Library) (2)
Commanding Officer and Director, U. S. Navy Underwater Sound Laboratory (Code 1450) (3)
Director, U. S. Naval Engineering Experiment Station (Library)
Director, U. S. Naval Research Laboratory (Code 2021) (2)
Director, U. S. Navy Underwater Sound Reference Laboratory (Library)
Commanding Officer, Air Development Squadron ONE (VX-1)
Commanding Officer, U. S. Fleet Sonar School, Key West
Commanding Officer, U. S. Fleet Sonar School, San Diego
Commanding Officer, U. S. Navy Mine Countermeasures Station (Code 712)
Commanding Officer, Office of Naval Research, Pasadena Branch
Commanding Officer, Surface Anti-Submarine Development Detachment, U. S. Atlantic Fleet
Hydrographer, U. S. Navy Hydrographic Office
Senior Navy Liaison Officer, U. S. Navy Electronics Liaison Office
Superintendent, U. S. Naval Postgraduate School (Library) (2)
Assistant Secretary of Defense (Research and Development) (Technical Library Branch)
Chief Chemical Officer, U. S. Army
Assistant Chief of Staff, G-2, U. S. Army (Document Library Branch) (3)
Assistant Chief of Staff, G-3, U. S. Army
The Quartermaster General, U. S. Army (Research and Development Division, CBR Liaison Officer)

Chief Signal Officer, U. S. Army (Engineering and Technical Division, Engineering Control Branch, SIGGD)
Commanding General, Aberdeen Proving Ground (Technical Information Branch)
Commanding General, Army Electronic Proving Ground
(Department of Electronic Warfare)
(Engineering and Technical Department)
Commanding General, Chemical Corps Research and Engineering Command
Commanding General, The Artillery Center
Commanding General, Redstone Arsenal (Technical Library)
Commanding General, Signal Corps Engineering Laboratories
(Administrative Div., Technical Documents Center)
Commanding Officer, Army Chemical Center (Technical Library)
Commanding Officer, Chemical Corps Chemical and Radiological Laboratories (Chief, Guided Missiles Branch)
Commanding Officer, Office of Ordnance Research
Commanding Officer, White Sands Signal Corps Agency (SIGWS-AD-2)
Chief, Army Field Forces (ATDEV-8)
President, Army Field Forces Board No. 1
President, Army Field Forces Board No. 4 (8576 AAU)
Resident Member, Beach Erosion Board, Corps of Engineers, U. S. Army

Deputy Chief of Staff, Development, U. S. Air Force (AFDRD-CC) (AFDRD-SC)
Deputy Chief of Staff, Operations, U. S. Air Force (AFOAC-P/F)
Commander, Air Defense Command
(Director of Communications and Electronics, AC&W Coordinating Division)
(Office of Operations Analysis, John J. Crowley)
Commander, Air Research and Development Command (RDDPA)
Commander, Air University (Air University Library, CR-5028)
Commander, Alaskan Air Command
(Director of Communications and Electronics)
(Chief, Operations Analysis Office)
Commander, Strategic Air Command (Operations Analysis)
Commander, Air Force Armament Center (ACGL)
Commander, Air Force Cambridge Research Center (CRQSL-1)
Commander, Air Force Missile Test Center (Classified Information Section)
Commander, Air Force Special Weapons Center (Air Force Atomic Energy Library)
Commander, Rome Air Development Center (RCRES-4C)

Commander, Wright Air Development Center (Technical Information Control Office, WCOSI)
Commander, Holloman Air Force Base (HDOTE-1)
Director, Armament Systems Personnel Research Laboratory, Air Force Personnel and Training Research Center
Chief, Los Angeles Air Force Development Field Office
University of California, Director, Marine Physical Laboratory, San Diego, California
University of California, Director, Scripps Institution of Oceanography (Library), LaJolla, California

VIA BUREAU OF SHIPS:

Executive Secretary (John S. Coleman), Committee on Undersea Warfare, National Research Council
Brown University, Director, Research Analysis Group
Massachusetts Institute of Technology
Director, Acoustics Laboratory (John A. Kessler)
Pennsylvania State University, Director, Ordnance Research Laboratory
The University of Texas
Director, Defense Research Laboratory
Military Physics Laboratory (Dr. R. B. Watson)
University of Washington, Director, Applied Physics Laboratory (Dr. J. E. Henderson)
The Director, Woods Hole Oceanographic Institution
Bell Telephone Laboratories, Incorporated, Murray Hill, New Jersey

Via Commanding Officer, ONR New York Branch:
Columbia University, Director, Hudson Laboratories, Dobbs Ferry, New York
Commanding Officer, ONR Boston Branch (Harvard University, Director, Acoustics Research Laboratory, Dr. F. V. Hunt)
Via ONR Resident Representative, University of Michigan:
University of Michigan, Director, Engineering Research Institute (Dr. J. R. Frederick)
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